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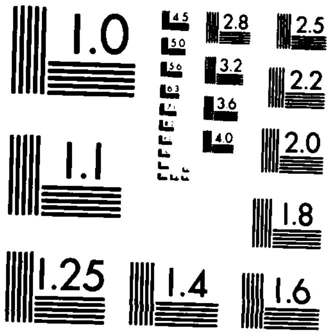

MICROCOPY RESOLUTION TEST CHART
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AD-A141 053

FTD-ID(RS)T-0122-84

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

UNDERGROUND ENGINEERING
(Selected Articles)

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MATHEMATICAL STATISTICS AND EXAMINATION OF THE STRENGTH OF INJECTED CONCRETE /22

Peng Jizhong

Concrete injection is an advanced, economically feasible, and effective new technology. It is widely used both here and abroad. The Cheng-kun Railroad Bureau has already utilized this technique in the building of lining of the arches and side walls of tunnels. The construction area reached over ten thousand meters.

In recent years, although the technological standard and familiarity have been improved in injecting concrete, which is the major construction item for the third engineering section of the bureau, however, there is still a significant discrepancy in the quality control (including testing). The major effect is the instability of the quality of the construction work. The phenomenon that the strength of injected concrete does not meet the specifications occurs very frequently. There is still a great potential to increase productivity and save materials. From the viewpoint of quality tests, comparing strength to thickness and appearance, strength is not only fundamental but also primary. Therefore, with respect to the strength of injected concrete, the important quality control tool - mathematical statistics - should be used in its management.

In this paper, commonly used mathematical statistical methods were introduced. In the meantime, based on the experimental data of that engineering section gathered over the years, a pattern for increasing the strength of injected concrete was sought through statistical analysis. The objective was to explore a method to test the strength in an early stage in order to change the examination method used for years. Furthermore, corresponding empirical formulas were derived to correlate the strength measured in an early stage to that of a later stage to facilitate the mathematical statistics

process. It also helped the testing of strength and improved its quality.

I. Mathematical Statistics

Mathematical statistics is a scientific management method based on the statistics of numbers. It can be used to grasp the dynamic state of quality, and to analyze and determine the problems present in quality. Various factors affecting the quality and their mutual correlations can be understood in order to control and adjust the major factors affecting the quality in time to fully utilize its potential and improve the quality.

1. Seven Commonly Used Methods

(1) Investigatory Statistical Table

It is used to investigate or collect various relevant data used in statistics.

(2) Classification Method

The data gathered is classified into groups, layers, and categories in order to find the problems present in quality control.

(3) Arrangement Diagram

With regard to the data related to the engineering quality, a linear column type of diagram is plotted according to the vertical coordinate after data collection and arrangement. These diagrams are helpful in the determination of primary and secondary factors affecting quality. Moreover, the major contradiction can be grasped and resolved.

(4) Cause and Effect Diagram

It is a diagram to express the cause and effect of a quality control problem in a simple fashion.

(5) Frequency Bar Diagram

Based on the data collected, the frequency of occurrence is statistically obtained. Then, according to the data and the frequency, a bar graph can be prepared. It is also called the frequency distribution bar graph. It is possible to project the qualifying rate of the engineering project by

using the frequency bar graph.

(6) Control Diagram

It is a curve showing certain characteristics of the quality, which contains a quality control evaluation line (or a control line). It is also called a management diagram. Usually, it is a dynamic plot of data according to the time sequence. In the diagram, a line of average is also plotted, with a determining line on either side. A control diagram can reflect the dynamic picture in the production process, which facilitates the dynamic analysis. A control diagram can have significant effect on the control and examination of the quality and the formulation of the work process.

(7) Distribution Diagram

The data points of two variables are plotted on a piece of paper with coordinates. The correlation between quality characteristics and factors affecting the quality are analyzed from the distribution of these data points.

In order to determine whether there is a correlation between a variable and the quality, and to find its mathematical expression and accuracy, it is sometimes necessary to carry out analyses by regression.

In addition, in the selection of mixing ratio, a multiple factor orthogonal optimization method can be used, which is also known as the orthogonal design.

2. Cause and Effect Analysis of Strength

The plotting of a cause and effect diagram classifies the factors affecting quality, which is helpful in analyzing and solving the problems. Furthermore, patterns are found through the comparison and accumulation of data to standardize the quality management.

Through an investigation, the factors affecting the strength of injected concrete are materials, mixing ratio, injection technique, and testing. The cause and effect diagram plotted is shown in the following.

When the symbol "Δ" is noted in the cause and effect diagram, it represents a relatively important influencing factor. These factors are further explained in the following.

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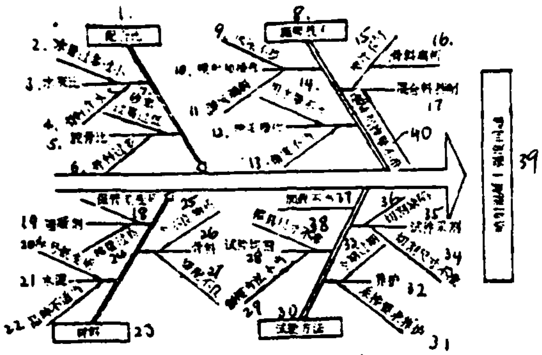

Cause and Effect of Injected Concrete Strength

1. mixing ratio
2. too much or too little water
3. water to cement ratio
4. aggregates containing too much water
5. colloid to aggregate ratio
6. too much aggregate
7. sand content too high
8. injection technique
9. unstable pressure
10. injection and operation
11. leaking pressure and materials
12. nozzle operation
13. improper angle
14. improper water amount
15. non-uniform mixing
16. aggregate separation
17. stirring of the mixture
18. deterioration due to poor storage condition
19. coagulant
20. degradation due to lower grade
21. cement
22. improper type
23. materials
24. excessively high amount
25. containing deleterious materials
26. aggregate
27. poor mixture

28. slicing of specimens
29. improper mould fabrication method
30. testing method
31. not cured according to requirements
32. curing
33. overdue
34. inaccurate slicing size
35. specimen cutting
36. cutting defect
37. improper loading
38. inaccurate mould size
39. strength problem of injected concrete
40. inadequate amount of setting accelerator

The water to cement ratio affects the tightness of injected concrete, which is most closely related to its strength. The water to cement ratio is actually controlled by the sprayer empirically. It differs from man to man. The dispersion in strength is very large and unstable. Therefore, it is very important to train experienced sprayers to improve the standard of the operation.

After the setting accelerator is added, the strength of concrete in the late stage is significantly affected. The strength of 28 day old concrete is usually 65-85% of that without adding the accelerator. Therefore, it is necessary to rigorously control the amount of accelerator added. Usually, it should not exceed 4% (according to information from the U.S., the strength would show a decreasing trend after 28 days if it is over 4%). It is appropriate to control it at 2-3%. Moreover, the quantity must be weighed accurately.

Injected concrete specimens, if prepared using the mould injection method, usually have a much lower strength than that in reality (the conversion formula will be discussed later).

3. Orthogonal Design of the Mixing Ratio Test

The selection of a mixing ratio used in construction requires many strength tests. The use of an orthogonal table to select the mixing ratio of injected concrete by orthogonal design will enable the finding of a mixing ratio for the present equipment and technology. Consequently, manpower and materials can be saved, and time can be reduced.

The objectives of quality improvement and scientific evaluation can be accomplished.

(1) Procedures in Orthogonal Design

The factors to be tested for the mixing ratio in construction are:

1) cement type, number, and amount
2) accelerator type and amount
3) sand ratio
4) water to cement ratio
5) amount of materials dusted away - another factor to be considered from the angle of savings.

According to the theoretical mixing ratio and the materials supply situation on the work site, usually two quantities (also called orders) are arranged for each of the five influencing factors mentioned above in the tests. With respect to factors which are more difficult to determine, more than two orders can be determined.

Based on the factors and orders already determined, the ((Multiple Factor Orthogonal Table)) in the book ((Commonly Used Mathematical Statistical Methods)) edited by the Statistics Group of the Institute of Mathematics of Academy of Sciences of China was chosen in the experiment.

(2) Experiment

Tests were carried out according to the arrangement and sequence in the multiple factor orthogonal table. After the tests, the results are listed on the right of the orthogonal table. Not only should the strength of each specimen be specified (standard age or the same age), but also the measured cement to aggregate ratio, cement to water ratio, rebounding rate, and single analytical numbers are noted to facilitate the analysis.

(3) Experimental Analysis

The sum of the strength values of order 1 and order 2 of each factor in the columns of the orthogonal table was calculated. Moreover, the order differential was figured out.

When the sum value of the order is large, it indicates that it is optimal to use this order for the factor. The optimal combination of orders chosen for each factor is the satisfactory mixing ratio for the construction work. Furthermore, economics and other factors are considered to determine the optimum mixing ratio for the construction work. Or, another test is conducted to verify it.

The magnitude of the order differe al indicates the influencing extent of the factor on its ntensity. When the order differential is large, then the e ect is large.

4. Example of Strength Analysis thematical Statistics

The experimental data obtained in the concrete injection project of the Fupiao tunnel on the Cheng-kun line was used as an example to be analyzed by mathematical analysis. The construction period began in February 1980 to March 1981. The mixing ratio of the injected concrete (theoretical) was 1:2:2. A rotor type injector was used. The cement was mostly No. 425 regular silicon cement. The water to cement ratio was 0.4. The experimental data statistics is as follows:

(4) Frequency Bar Diagram

Due to the fact that the ages of the specimens were not the same, they were converted to the standard aged strength of 28 days to facilitate the statistical analysis. The conversions of aged strength within 28 days and over 28 days were carried out using equations (2) and (4) derived later in this paper, respectively. The 28 day average strength value R28 at the work site was 229 kg/cm^3.

Under the normal construction condition, the strength of injected concrete followed a normal distribution. Now, the data in the table above was divided into 10 groups. The calculation is as follows:

1) group spacing R = 306-164 = 142

2) difference (10)h = 142 $\div$ 9 = 15.7 $\approx$ 15

3) frequency table listed for the calculation (omitted)

4) calculating strength average $\overline{X}$ and standard deviation S

$$\overline{X} = \frac{\Sigma f i \mu i}{\Sigma f i} \times n \times X_o = 222.2\ (kg/cm^2)$$

$$S = \sqrt{\frac{1}{\Sigma f i} [\Sigma \mu i^2 f i - \frac{(\Sigma \mu i f i)^2}{\Sigma f i}} \times h = 7.76\ (kg/cm^2)$$

The average strength value and standard deviation are used to evaluate the quality level. The average construction strength should be higher than the designed strength (200 level). It is pre-determined according to the construction standard. The computation formula is $f_{cr} = f_c' + t\sigma = 200 + 1.04\sigma$.

Where: f_{cr} is the average strength required by the construction work, f_c' is the designed strength = 200 kg/cm^2, and t is the probability index of quality control. According to the technical standard, the allowable probability lower than the designed strength is 15%, where t = 1.04. σ is the estimated standard deviation.

Statistical Table of Strength of Injected Concrete of Fupiao Tunnel on the Cheng-kun Line /24

次序号 1.	顺 号 2.	试验日期 3.	试件 4. 强度 5.				试验龄期 7.	折合28天强度 8.	同日平均强度 9.	3组平均强度 10.
			1	2	3	平均强度 6.				
1	2	3	4	5	6	7	8	9	10	11
		1980.								
1	1	2.1	236	310	310	285	37	280	280	
2	2	2.9	165	180	190	178	120	164	164	
3	3	2.10	210	200	210	207	120	191	191	
4	4	2.17	210	210	210	210	112	194	194	
5	5	2.19	225	230	240	232	110	215	215	209
6	6	3.11	240	230	230	233	88	218	218	196
7	7	3.15	155	220	240	205	85	192	193	202
	8	11	230	185	210	208	85	195		203
8	9	3.17	220	230	240	230	83	216	216	270
9	10	3.27	175	200	190	188	73	178	178	200
10	11	2.28	215	195	230	213	71	202	193	197
	12	11		201	206	204	169	184		195
11	13	4.1	200	210	220	210	68	199	199	196
12	14	4.2	220	210	240	223	67	211	211	195
13	15	4.19	155	215	240	203	50	196	196	198
14	16	4.20	230	205	215	217	50	209	209	200
15	17	4.30	200	250	230	227	40	222	222	207
16	18	5.4	250	270	240	253	36	249	249	217
17	19	5.17	205	230	200	212	55	204	204	216
18	20	5.19	245	195	200	213	53	205	205	218
19	21	5.23	220	210	216	215	86	202	202	216
20	22	7.4	202	206	189	199	45	193	203	211
	23	7.4	240	210	210	220	45	214		205
21	24	7.30	190	189	191	190	20	205	201	205
	25	7.30	182	180	180	181	20	195		203
	26	7.30	190	190	183	188	20	202		203
22	27	8.14	231	235	230	232	53	223	223	290
23	28	8.17	231	232	235	233	50	225	225	211
24	29	8.24	235	235	240	237	43	231	231	216
25	30	9.31	220	225	215	220	34	217	217	221
26	31	9.28	270	285	275	277	53	267	267	235
27	32	10.4	260	308	370	313	46	304	272	249
	33	10.4	240	250	255	248	46	241		252
28	34	10.10	236	240	266	247	40	241	241	254
29	35	10.10	185	192	232	203	39	199	199	250

1. sequence
2. number
3. test date
4. specimen
5. strength
6. average strength
7. testing age
8. converted
9. average strength on the same day
10. cumulated average strength among 5 groups

/25

1	2	3	4	5	6	7	8	9	10	11
30	36	10.20	235	240	240	238	28	238	222	245
	37	10.20	170	210	240	207	30	205		225
31	38	10.21	265	267	315	282	28	282	282	233
32	39	10.30	225	220	240	228	28	228	228	230
	40	11.30	266	266	222	231	35	228		236
33	41	12.3	175	216	260	217	20	234	240	235
	42	12.3	245	260	250	252	45	245		243
34	43	12.9	166	155	130	150	14	177	205	222
	44	12.9	265	260	255	260	65	247		226
	45	12.9	265	180	170	205	90	192		219
35		1981.								
	46	1.17	320	305	300	308	30	306	279	233
	47	1.17	255	270	240	255	30	253		235
36	48	1.29	251	295	257	268	28	268	268	253
37	49	1.30	238	270	265	258	28	258	258	255
38	50	3.21	255	275	260	263	28	263	263	270

2. 组号K	3. 组距起止值 (n)	4. 中心值 Xi	频率 5. fi	标志 6. fi①	ui ②	fiui ③ = ① × ②	ui^2fi ④ = ② × ③
1	162.5~177.5	170	7 下	2	-2	-4	8
2	177.5~192.5	185	8 正	5	-1	-5	5
3	192.5~207.5	200	9 正正正	14	0	0	0
4	207.5~222.5	215	10 正 下	8	1	8	8
5	222.5~237.5	230	11 正 一	6	2	12	24
6	237.5~252.5	245	12 正 一	6	3	18	54
7	252.5~267.5	260	13 正	4	4	16	64
8	267.5~282.5	275	14 下	3	5	15	75
9	282.5~297.5	290		0	6	0	0
10	297.5~312.5	305	15 丅	2	7	14	98
			Σfi	50		74	310

1. table continued
2. group number
3. starting and ending value of the group
4. median value
5. frequency
6. frequency
7. 2
8. 5
9. 14
10. 9
11. 6
12. 6
13. 4
14. 3
15. 2

Based on the present construction level in our section, it can be selected in the 15-25 range.

(5) The frequency bar diagram plotted is as follows:

From the frequency bar graph plotted one can see that: the frequency distribution was not concentrated. It extended toward the sides. Furthermore, the upper and lower limits of quality control were violated (3 times the standard deviation), which indicated that the concrete injection work was in an unstable state.

The frequency peak leans toward the left of the mean strength line, indicating the strength was lower. Moreover, there were unqualified specimens. This should be taken seriously, and effective measures were implemented in order to shift the center of frequency distribution to the mean value line to form a normal distribution.

(2) Control Diagram

The frequency bar graph is capable of reflecting the status of strength and the problems present. However, it is not possible to see its changes and development. This requires the further plotting of a control diagram to slow the dynamic state of strength and the developmental trend in order to facilitate the evaluation of the stability in the production process. It is used to inspect and predict the presence of unqualified products so that the technology can

be improved and the quality is raised.

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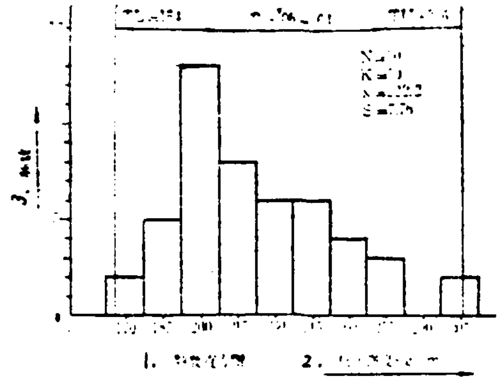


1. Frequency Bar Graph
2. pressure resistant strength kg/cm^2
3. frequency

Usually, there are three types of control diagrams for the strength of injected concrete:

1) Single group experimental strength diagram or individual experimental strength diagram - i.e., to plot the results of strength tests according to the sequence in which the specimens were taken. Furthermore, the average strength line or the average strength line for the construction work, as well as the upper and lower limits, were indicated.

The upper and lower limits were calculated based on the mean strength X, plus and minus 3 times the standard deviation S:

$X \pm 3S = 222.2 \pm 3 \times 7.76$

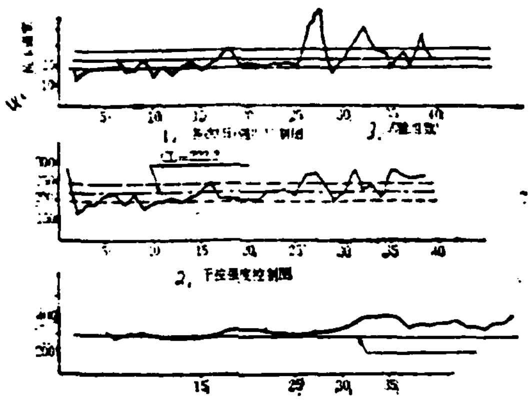
LCL = 198.92 kg/cm^2, VCL = 245.48 kg/cm^2.

2) Average strength diagram - to be plotted by the average strength values in the first 5 groups. According to the standard of the present construction work, it is possible to recommend the lower limit of the specified design strength.

3) Average difference dynamic picture - to be plotted by the average differences among the same group of blocks for 5 or 10 groups in order to determine whether the specimen fabrication method or experimental procedure is appropriate. Because the differences between extremes in the data listed in the statistical table were too large, no graph was plotted. Only the first two types of diagrams are prepared as follows.

From the overall development point of view, strength was developed from a low level to a relatively high one by analyzing the single group, individual, and average strength control diagrams. However, it was not stable. Because specimen testing was not carried out and quality control was not intensified in time, it was located at a low level for quite a long time. In the early stage, there were products which did not meet the quality specifications. The strength of a representative group in the concrete injection construction section was lower than 85% of the design specification. A reinforcement measure should be taken.

Combining the construction technological regulation with the overall analysis of the frequency bar graphs, the lower limit of the quality control in strength LCL = 198.92 kg/cm^2, which was very close to the specified design strength of 200. There were 7 groups lower than this limit, which was 14% out of the total number of 50. The specification required 15%. Therefore, it basically qualified (if calculated with the actual number of groups, then it was slightly higher than 15%). The mean strength value X = 222.2 kg/cm^2 (standard deviation S = 7.76 kg/cm^2 which is considerably small) is not very high. If the average strength predicted for the construction work was selected, it should be slightly increased. It is more appropriate to be about 225-230 kg/cm^2.



1. individual (day) strength control diagram
2. dry tensile strength control diagram
3. tested group
4. pressure resistant strength

II. Examination

With regard to the examination of the strength of injected concrete, the design and construction technological regulations specify that the pressure resistant strength is the primary one to be checked. This is because the pressure resistant strength of injected concrete is an overall indicator affecting its physical mechanical characteristics and durability. It is also significantly related to its working characteristics and application effectiveness. Only when special requirements are called for in the design, other characteristics are examined.

1. Examination Method

The examination of the pressure resistant strength of injected concrete has destructive and non-destructive testing methods.

In recent years, many non-destrcutive methods emerged abroad. In China, there is no practical way to perform non-destructive tests. Only a rebounding device is available, which has not been perfected for testing. Therefore, it has not yet been adopted by the relevant technical standards. Hence, only destructive tests are used in China at the present time.

A large injected slab cutting method is used to prepare the strength test specimens according to the technical standards. When there is doubt about the strength, a saw tooth cutting method may be used.

No matter whether the large slab cutting method or the saw tooth cutting method is used, it is necessary to have some cutting equipment. Presently, such equipment cannot be popularized because of the small number produced and the high cost. Furthermore, the disturbance of any cutting method is large. It is difficult to prepare specimens in an early stage, which brings about extreme difficulties in the prediction of strength. Therefore, there is a need to find a simpler method to prepare specimens, i.e., to use the conventional testing mould method. The preparation of specimens by the mould injection method is not limited by the cutting equipment. It is easily feasible. It is especially worthwhile to point out that it is easy to obtain perfect super early stage specimens of a few hours. The disadvantage is that the compactness and integrity of the specimen prepared is affected by the small injection area and the limited injection angle. The measured strength is lower than the actual strength and that of specimens prepared by the cutting method. However, there are still patterns to follow, i.e., the correlation between them can be found through comparative tests. The strength of injection mould specimen could be adjusted to reflect the actual strength. Thus, it is not only possible to fabricate injected concrete specimens under the condition without any cutting equipment, but also saves capital

investment, lowers costs, and facilitates the fabrication.

Under the condition that the raw materials and construction techniques were identical, injected mould and cutting specimens were prepared simultaneously for the Xiakeng tunnel. Six groups of each were fabricated (each group included 3 blocks), and they were cured for 28 days in the standard condition. Moreover, the standard testing method was used to examine them. /27

The correlative expression is:

injection mould strength x 1.307 = cutting method strength

Through a square deviation analysis, it was calculated that $F = 6.02 > 4.96$ (the assurance rate is 95%). This indicates that the effect on strength is significant when the fabrication method and size of the two types of specimens are different.

The injection mould specimen mentioned above was cubic. Presently, a cylindrical iron mould is available in China. The expression for the correlation between these two types, according to the information on the testing of regular concrete in Japan, is:

1. 龄期	2. 圆柱体		3. 立方体
	4. ϕ15×15厘米	5. ϕ15×15厘米	6. 15厘米
7. 28天	1.12	1.00	1.16

1. age
2. cylindrical
3. cubic
4. Ø15 x 15 cm
5. Ø15 x 15 cm
6. 15 cm
7. 28 days

The measured strength is inversely proportional to the height of the testing mould. The difference between the strength of the 15 cm high cylinder and that of the cubic testing mould is very slight. However, the compactness of injected concrete specimens is better without corners. Therefore, the 15 cm high cylinder can be considered to be identical to the cube. There is no need for further conversion.

Due to limited amount of experimental data and narrow surface, the correlative coefficients derived are only used as a reference. However, they are worthwhile to be further studied. After more data is gathered and correlative coefficients are obtained from analysis, it will be recommended to the relevant departments as a method to examine injected concrete.

2. Conversion to Standard Age Strength

According to the specifications in the design and construction technological regulations, the pressure resistant strength of injected concrete is tested after curing the test specimens for 28 days. The examination specified after 28 days is a typical test after the fact, which does not meet the overall requirements in quality control. It is not only impossible to test the strength in time, but also unfavorable to the prevention of unqualified products. When unqualified test specimens begin to emerge, the construction has already been completed for nearly one month. It is too much trouble even to undergo a reinforcement process. Therefore, from the viewpoint of overall quality control, it is not only necessary to find a method to prepare and examine specimens in an early stage, including the use of the non-destructive rebounding device, but also it is required to derive a formula to calculate the rate of increase in the early stage and its conversion to the standard age. On the other hand, because cutting machines are not widely available, it is necessary to send large injected slabs to places with the cutting equipment to be

processed and tested. On top of that, due to few pieces of equipment and large number of specimens, those tested frequently have already exceeded the standard age. The technical guideline in practice has not been involved with the problem of overdue tests. There is research data on the strength increase in a late stage and its conversion to the standard age strength. In a tunnel repair project in China, argument occurred on the conversion problem because the test data was obtained with the overaged specimens, causing the inspection work upon delivery to be very difficult. Hence, the conversion of overaged strength is also a worthwhile and urgent matter to study.

(1) Early Stage (within 28 days) Strength Increase Rate and Conversion Formula to the Standard Age Strength.

Now, the early stage strength test data obtained in the construction of the Nujiaoshan tunnel and the Xiakeng tunnel is tablulated in the following:

1. 隧道名	2. 强度	3. 龄期（小时）						
		8	16	6. 24（1天）	7. 48（2天）	8. 96（4天）	9. 168（7天）	10. 672（28天）
4. 牛角山隧道(1972)		23	56	85	143	172	186	245
5. 下坑隧道(1979)		24	53	66	105	142	175	227

1. tunnel name
2. strength
3. age (hours)
4. Nujiaoshan tunnel (1972)
5. Xiakeng tunnel (1979)
6. 24 (1 day)

7. 48 (2 days)
8. 96 (4 days)
9. 168 (7 days)
10. 672 (28 days)

According to a regressive analysis of the Xiakeng data mentioned earlier, an expression for the rate of increase of early stage strength was obtained as:

$$R = 110.37 \log T - 77.25$$

Through a square deviation analysis, it shows that the effect of age on the pressure resistance strength is "especially significant". The regression line is good.

A correlative analysis was performed with respect to the two sets of data mentioned above. It shows that there is no significant difference between the two sets of data. The early stage strength increase rate formula was corrected to be:

$$R = 114.35 \log T - 76.69 \qquad (1)^*$$

By using this early stage strength increase rate expression, the following standard age strength conversion formula can be derived:

$$\frac{R_{28}\,(\text{early})}{\bar{R}_{28}} = \frac{R_T}{114.35 \log T - 76.69 - (246.6 - \bar{R}_{28})} \qquad (2)$$

Where: T-age, in units of hours; R_T-actual strength at the age of T hours; and $\bar{R}_{28}$-average strength value at the work site at the standard age.

Because adjustments were made by using various average strength value at the work sites and the 28 day strength of 246.6 kg/cm^2 in the above formula, therefore, equation (2) can be recommended as an empirical formula.

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*Note: Formula (1) was adopted from the information provided by comrade Zhang Jiashi of the Institute of Design at the Ministry of Railroads.

(2) Late Stage (28-120 days) Strength Increase Rate and Its Standard Age Strength Conversion Formula

The test data was collected by summarizing the test reports on the late stage standard specimens prepared by the third engineering section in our bureau in recent years. The average strength values were obtained according to the age. In order to facilitate the calculation, 5 groups were chosen for each age to be tabulated statistically in the following.

From the statistical table one can see that although the rate of increase in strength of concrete in the late stage is far less than that in the early stage, it still increases with age and varies linearly.

The average strength value at the same age (combining 25 groups into 5 groups) was used for regressive analysis, and we get: /28

$$\bar{X} = \frac{\Sigma X}{n} = 1.772 \text{ (logarithmic value)}$$

$$b = \frac{LXY}{LXX} = 30.33$$

$$a = \bar{Y} - bX = 185.66$$

The regressive equation is: $Y = a+bX$.

Based on the assumed condition $Y = R$ (strength), $X = \log T$ (logarithm of age), the rate of increase in strength at the late stage can be rewritten as follows from the above formula:

$$R = 185.66 + 30.33\log T. \qquad (3)$$

The 25 groups of strength data tabulated were used in the calculation of the correlation coefficient (using the same method as before and it is omitted). The result is:

$$r = \frac{LXY}{\sqrt{LXX \cdot LYY}} = \frac{39.112}{\sqrt{1.305 \times 2226.24}} \qquad \text{(A)}$$
$$= 0.726$$

By checking the correlation coefficient table, with n= 25, it is 0.396 when the significant level is 5%, and it is 0.505 when the significant level is 1%. r = 0.726 is larger than the 2 values given above (the closer Y approaches 1, the more closely X and Y are correlated linearly), which indicates that it is above the 1% level. The correlation between X and Y, i.e., age and strength, is apparent. Therefore, the assigned straight line has its significance. The reflected late stage strength increase rate is valuable.

A calculation of the accuracy of the regression line showed that the remaining standard deviation is:

$$S = \sqrt{\frac{1}{n-2}(1-r^2)LYY} = 6.766 \qquad \text{(B)}$$

Based on a normal distribution, the probability that the strength value is distributed in the ±2S range is 95.4%. The error is ±2S = ± 13.53 kg/cm^2.

According to the rate of increase in equation (3), the conversion formula to the standard strength from a late stage was derived to be:

$$R_{28(\text{折})} = \overline{R}_{28}\,\frac{R_T}{185.66 - 30.33\log T - (229 - \overline{R}_{28})} \qquad (4)$$

Where T-age, in the unit of days; R_T-actual strength at age T; and $\overline{R}_{28}$-average strength in 28 days tested on site.

In the statistical analysis of the injected concrete strength values obtained in the construction of the Fupiao tunnel on the Cheng-kun line mentioned earlier in this paper, because of the age many specimens, the strength values were measured too early or too late. Equations (2) and (4) were used, respectively, to convert those values to the standard age values to allow the mathematical analysis to proceed.

Otherwise, it could not be carried out. Moreover, the converted strength values were satisfactory, which approached the actual standard age strength.

1. 编号	2. 龄期（天）	3. 抗压强度（公斤/厘米²） 1	2	3	4. 平均强度	5. 组平均强度（公斤/厘米²）
1		270	235	200	233	
2		205	215	235	218	
3	28	235	240	240	238	229
4		—	215	225	220	
5		235	240	240	238	
6		250	200	230	226	
7		220	235	244	233	
8	40	235	235	240	237	235
9		270	205	240	235	
10		240	250	245	245	
11		240	230	250	240	
12		235	245	—	240	
13	60	245	250	260	248	240
14		230	230	245	235	
15		223	243	240	235	
16		245	230	250	242	
17		250	260	235	248	
18	90	235	270	250	251	244
19		255	240	250	248	
20		240	230	230	233	
21		230	270	240	247	
22		240	250	255	248	
23	120	200	260	260	240	249
24		230	240	290	253	
25		235	310	225	257	

Statistical Table of Strength from 8 - 120 days

1. sequence number
2. age (days)
3. pressure resistance strength (kg/cm^2)
4. average strength
5. average group strength (kg/cm^2)

REPAIR AND REINFORCEMENT OF CRACKS AND DEFORMATION OF UNDERGROUND ENGINEERING ALREADY IN PLACE /29

Xianyu Fanggeng

Due to unknown geological hydrology, improper positioning, irrational design, poor selection of materials, bad construction quality, and improper maintenance, ring-shaped, radial and longitudinal cracks could be produced. Some of the brick surface is weathered, loose, and peeling. Some of the plastered surface cracks, bulges, and peels. In some cases, the floor bulges, the side wall swells, and the ceiling fractures. There is the danger of collapsing, which causes the protective capability and integrity of the underground construction project to fail its requirement. The water leak is so serious that it is impossible to hide people during the war, and to use during peace time. Some of the underground projects have begun to collapse, which endangers surface buildings and traffic safety. In some cases, the entire underground construction is wasted. For this reason, an investigative study was carried out on the cracks and deformation in underground structures. According to the time and location, the corresponding repair and reinforcement measures can be adopted. Now, the specific procedures are described as follows:

Causes for Cracks and Deformation

There are many reasons for cracks and deformation to occur in underground structures already in place. They can be summarized in four major areas:

I. Improper Position of the Structure: Due to the lack of geological hydrology drilling data in the survey, some of the underground structures are located in soft soil. The concrete structure is significantly affected by a relatively large temperature difference and changes in humidity. Some of the underground projects are located in areas where a sharp difference between a soft rock layer and a hard one exists. The structure is sinking in an uneven manner,

leading to the formation of annular unstable cracks. They usually appear at the junction between the main body of the structure and the entrance and exit, the static load boundary points, or transverse construction seam positions. The axis of an underground structure is parallel to the many thin rock layers. The inner layer slides downward, causing a pressure to develop. Some of the underground structures are situated in poor soil. The foundation is softened due to the effect of permeation of a large amount of surface water and underground water, causing the foundation to sink. It will lead to longitudinal cracks, which usually appear at the vault, the arch support, and the side wall in an underground engineering project. When an underground engineering structure is located in saturated sand soil or a landfill, a dry hole is created due to the pumping of water year round. In some cases, the structure is affected by an asymmetric earthquake force. These will create radial cracks in the structure. They usually appear on the floor, vault, and corners in the structure.

II. Improper Design Calculation: Using straight wall and flat floor in a soft soil area with a large pressure from the side, adopting a red brick construction for the foundation of underground engineering structure in a high water level area, using joints with a sharp angle less than 60° without taking measures to reinforce it, insufficient structural strength or stability due to a thin structure and low strength in the structure, and displacement of supports of a large span underground project due to a horizontal force, will lead to cracks and deformation in the structure.

III. Poor Construction Quality: Cracks are created because lateral and longitudinal construction seams were not treated in a large volume underground concrete structure. Freshly poured concrete with a high water to cement ratio will cause voids in the structure. In some cases, the backfill is not compact and homogeneous, and the mould was

removed too early. These are the reasons causing the fracture and deformation of an engineering project. A brick structure is weathered, weakened, and flaking off because of the poor construction quality and the influence by the underground environment. The plastered layer of some underground srtuctures was not put on tightly. The bonding is not secure and the contact is not good. After plastering, in some cases, it is not maintained properly. These are the reasons to cause cracks and bulges.

IV. Improper Maintenance and Management: there are no special people in charge of the underground projects already built. When minute cracks begin to appear in the structure, repairs cannot be done in time. They are left alone. The steel bars are corroding and the structure is deformed. When the water accumulated in surface buildings is not treated and leaky sewer pipes are not repaired, water begins to penetrate the coverage layer of the underground structure, leading to structural damage. When one side of a shallowly buried engineering structure is used as the foundation of a multi-level building, and when heavy vehicles are driven freely on top of the vault, fracture and deformation of the underground engineering project will be caused.

Methods to Find the Causes

In order to grasp the actual situation of cracking and deformation in an underground structure, before treating them, experienced engineering technical personnel should be invited to conduct an overall study to accurately pin point the causes so that effective measures to repair and reinforce can be taken in time. Usually, it is possible to use methods including investigating, visiting, observing, listening, measuring, and drilling.

I. Investigating: to find original information and diagrams during the construction of the underground project, such as the geological hydrology drilling data, construction diary, inspection records when the concrete was poured, record of inspection upon completion, certificate of

engineering quality, structure calculation, design and completion diagrams.

II. Visiting: to visit the technicians and workers who participated in the original construction work,to understand the situation of materials selection, mixing ratio, mixing, firming, mould removal, and curing during construction, as well as the actual structural thickness, steel bar diameter and opening, through the memory of those people.

III. Observing: to use a piece of thin paper, or to insert a thin plate into the crack to determine whether there is any new development of the crack periodically by the naked eye. A small hammer is used to hit the surface of the concrete in order to observe the depth of the marks by the naked eye to determine the strength of the concrete.

IV. Listening: to use a small hammer to tap the plastered layer back and forth in an orderly manner and listen to the sound. When the sound turns dull, it is usually a bulge, which should be labeled and repaired.

V. Measuring: to use a transit compass and a level to specify the direction and height of the deformed portions and to grasp the sinking and displacement situation in time. The width of the crack is measured with a microscope. The depth of the crack and its running direction can be detected by injecting colored water. The strength of a deformed structure can be measured by using a rebounding device or an ultrasonic detector.

VI. Drilling: to drill holes to measure the thickness and compactness of the structure for cracks and deformation in important positions. The concrete strength can be measured /30
by chiseling. When the conditions exist, photography and television techniques can be incorporated into the hole drilling process.

When larger fractures and deformations exist, fixed observation stations should be installed. Special people are assigned to periodically observe and record data in order to facilitate the timely analysis of the causes and to

adopt the corresponding reinforcement measures.

Methods to Repair and Reinforce

The cracking and deformation of an underground structure already built are mutually affecting each other. Excessive deformation of the structure may lead to corresponding cracking. Very large cracks may further increase the deformation. Therefore, it is necessary to control the cracks in time to prevent the deformation of the structure. Presently, there are many methods to repair and reinforce. A specific analysis should be performed according to the actual situation and the problem should be treated case by case. The principal concerns are to satsify the requirements in safety, reliability, utilization during both war and peace time, reasonable cost, and convenience in construction.

I. Repair: Only when the rate of development is very slow for the deformation of an underground engineering project, or when it is basically stabilized and does not continue to develop, then repair work shall proceed. The method to repair should be determined by the nature, direction, water leakage, engineering requirement, and construction condition. The propagation of cracks is then stopped to prevent the deformation of the structure.

1. Repair of Stable Cracks in Underground Structures Already Built

A trapezoidal groove is chiseled along the crack. The groove is 2-3 cm deep and 3 ~ 4 cm wide. A steel brush is used to brush away the powder. Clean water is used to rinse and wet the surface.

(A) Cracks without Water Leakage: A 2 mm layer of pure cement (water to cement ratio 1:0.33) is first put on. Then, a cement and sand mixture (cement:sand:water = 1:2.5:0.42) is used to spread on it flat.

(B) Cracks with Water Leakage:

(1) Cracks with Relatively Low Water Pressure: A method to first plug the leak and then do the waterproof work is adopted. Cement is mixed into an alumina waterproof sealant according to the specification to form a cement gel. It is shaped into strips. When it begins to coagulate, it is rapidly pressed into the groove with fingers tightly. Then, a layer of pure cement and a layer of sand mixture are applied. The surface is smoothed. After the sand mixture has obtained a certain strength (24 hours), five layers of waterproof coatings are applied. If the crack is too large, leak plugging and waterproofing can be done by sections.

(2) Cracks with Relatively High Water Pressure: A method to drain water from the inside and waterproof from the outside is used. A semi-circular plastic pipe (rubber pipe, galvanized steel pipe, bamboo pipe) is buried under the groove. The width of the pipe is equal to the bottom of the groove. The pipe is led to the drainpipe. Cement is filled on top of the pipe and five waterproof coating layers are applied (See Figure 1).

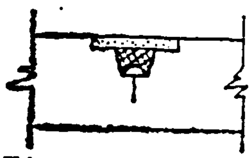

Fig. 1.

2. Repair of Unstable Annular Cracks in Underground Structures Already Built

A 15-20 cm wide, 3 cm deep flat bottom V-shaped groove is chiseled along both sides of the annular crack. Underneath this groove, a 8-10 cm deep, 7-8 wide U-shaped groove is made (See Figure 2).

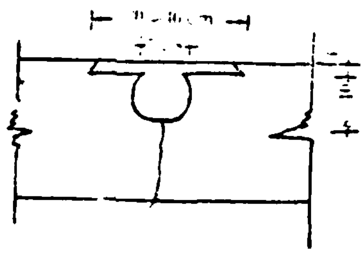

Fig. 2.

(1) The U-shaped Groove Treatment:

(A) Cracks Without Water Leakage: A pure cement layer 2-3 mm thickness, is first applied to the groove. A crushed stone concrete (cement:sand:small gravel = 1:1:2) is used to fill it up (See Figure 3).

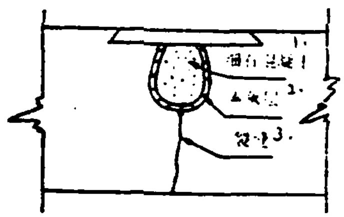

Fig. 3.

1. crushed stone concrete
2. pure cement
3. crack

(B) Cracks With Water Leakage:

(1) Cracks With Relatively Low Water Pressure: Latex cement is directly applied to the crack to plug the leak. Then, a 2-3 mm pure cement layer is put on. Finally, it is filled with a cement-sand mixture (cement:sand=1:1.5) (See Figure 4).

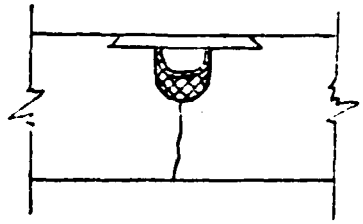

Fig. 4.

(2) Cracks with Relatively High Water Pressure: A water diversion pipe is buried on the bottom of the groove. It is also led into a drainage pipe. After the leak is plugged by filling the outside of the pipe with latex cement, a pure cement layer is applied. Finally, a 1:1 cement to sand mixture is used to fill the gap (See Figure 5).

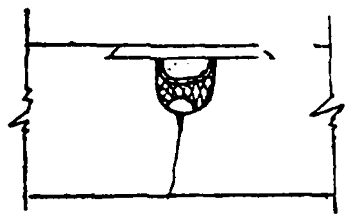

Fig. 5.

II. The Flat-bottom V-shaped Groove Treatment: After 2-3 hours from putting a pure cement layer on the flat bottom, a 1 cm thick layer of 1:1.5cement to sand mixture is applied. The pure cement and sandy cement layers are repeated until the required thickness is reached. As the cement sand mixture is pressed and smoothed, it is brushed several times in 2-3 hours. Then, it undergoes five steps, i.e., washing, glue preparation, glue brushing, binding, and masking, to be integrated into the foundation by a chloroprene rubber adhesive /31 band.

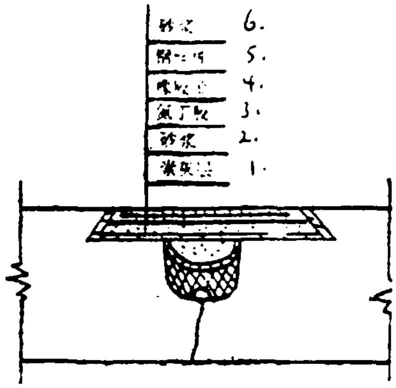

Fig. 6.

1. pure cement layer
2. sand-cement mixture
3. chloroprene glue
4. rubber band
5. steel mesh
6. sand-cement mixture

3. Repair of Cracks and Bulges on Large Surface Coating

Remove the cracked and bulged coating and clean the foundation well. An overall inspection for water leakage should be done in order to seriously take care of the waterproofing work. After the structure is stabilized, the five coats will be applied strictly according to the operating manual.

II. Reinforcement: When the rate of deformation of an underground structure gradually increases, it is an unusual sign. One should continuously observe and measure, as well as take proper measures to reinforce it in time. The reinforcement method, however, should depend on the situation of the crack and deformation of the structure, the space underground, the construction condition, and the economics. The objective is, of course, to ensure the safety in its use.

1. Slurry Injection Reinforcement

(1) Granular Materials for Slurry Injection. It is primarily used to fill the voids outside the coverage layer so that the force on the structure is homogeneous. It reduces erosion of the structure by water and increases the

durability of the structure. After the structure is stabilized, the cracks can then be repaired or reinforced.

(A) Treatment of Holes Under the Floor

(1) Without Underground Water Effect: The foundation can be fortified by sand using pressurized water. Materials selection: clean river sand or mountain sand. The grain size should not be larger than 3mm. The silicate cement label should not be lower than 300*. The ratio is: water:sand=1.5-2:1.

(2) With Underground Water Effect: Water and sand can be used in the middle. A cement-sand slurry can be injected all the way around to form a curtain to reinforce the foundation. Mixing ratio: cement sand mixture:cement: sand=1-2:1, Water to cement ratio 0.5-0.7. Water and sand: same as before.

(B) Treatment of Voids Outside the Side Wall: A clay slurry or a slurry-cement slurry can be used to backfill the voids. Materials selection: clay, specific gravity 2.65-2.5, plasticity limit 10-25%, grain size less than 0.2 micron. The technical requirements of cement are the same as above. Mixing ratio: clay slurry:water:clay=1.2:1. Clay-cement slurry:water to cement ratio 0.8-0.9. The amount of clay used is 10-15% of that of cement.

(C) Treatment of Voids on the Vault: When conditions allow, holes can be drilled from the ground level and sand can be used to backfill the voids. When conditions do not permit, pipes can be buried by drilling holes in the covering layer to send pressurized cement slurry (with respect to the voids outside the support) to backfill the voids. Mixing ratio: sand-cement slurry:cement:sand=1-2:1, water to cement ratio is 0.5-0.7.

(II) Chemical Injection Slurry: It is primarily used in the plugging of water leaks and reinforcement with respect to voids and cracks (crevice less than 1mm) in the structure.

(A) Type C Slurry: It is used in minute cracks with water seepage and in the reinforcement of sinking (tensile) fractures. The mixing ratio of the slurry is as follows:

1. 水泥浆:

2. 水灰比					
	3. 稀浆	2:1	1.5:1	1.25:1	1:1
	4. 浓浆	0.8:1	0.75:1	0.6:1	0.5:1

5. 甲 液

6. 材料名称	7. 丙烯酰胺	8. 亚甲基双丙烯酰胺	9. 三乙醇胺	10. 水
11. 所占百分比 (%)	18.9	1.0	0.7	79.4

12. 乙 液

13. 材料名称	过硫酸铵 14.	水 15.
16. 所占百分比 (%)	0.7	99.3

1. cement slurry
2. water to cement ratio
3. dilute
4. concentrated
5. solution A
6. material
7. propenyl amine
8. methyl dipropylamine
9. triethanol amine
10. water
11. percentage (%)
12. solution B
13. material
14. ammonium persulfate
15. water
16. percentage (%)

(B) Type A Injection Slurry: It is used to reinforce the cracks in a concrete structure.

1. 材料名称	3. [illegible]	5. 过氧化二[illegible]	7. 二甲基苯胺	9. [illegible]甲苯亚磺酸	11. [illegible]	13. [illegible]
2. 用量	4. 100毫升	6. 1~1.5克	8. 0.5~1.5毫升	10. 0.5~1.0克	12. 0~0.1克	14. 15~18毫升

Mixing Ratio of the Slurry Material

1. material
2. amount
3. methyl methyl propionate
4. 100 ml
5. dibenzo peroxide
6. 1-1.5 g
7. dimethyl aniline
8. 0.5-1.5 ml
9. p-toluene sulfonic acid
10. 0.5-1.0g
11. fuming gallic acid
12. 0-0.1g
13. ethylene acetate
14. 15-18 ml

(C) Epoxy Resin Injection Slurry: It is used to reinforce the cracks created by localized destruction.

1. 材料名称	2. 6101号环氧树脂	3. 糠醛	4. 丙酮	5. 多乙烯多胺
6. 重量	7. 100克	8. 35克	9. 35克	10. 22毫升

Mixing Ratio of the Slurry Material

1. material
2. No. 6101 epoxy resin
3. furfural
4. acetone
5. polyethylene polyamine

6. weight
7. 100 g
8. 35 g
9. 35 g
10. 22 ml

(D) Polyurethane and Cement Injection Slurry. It is to be used in the reinforcement of cracks in a relatively large underground structure, which is very effective.

1、材料名称	2. 聚氨脂预聚体	3. 苯二甲酸二丁脂	4. 丙酮	5. 吐温-80	6. 水泥（普通硅酸盐）
6、重量比	100	10	10	:	50～80

Mixing Ratio of Slurry Materials

1. material
2. polyurethane precursor
3. dibutyl phthalate
4. acetone
5. tuwen-80
6. cement (regular silicate)
7. weight ratio

2. Floor Reinforcement /32

In treating the cracks and deformation of an underground engineering project, reinforcing the floor is the key to stabilizing the entire underground structure. It is an important aspect affecting the success of the treatment. Therefore, in the entire treatment, we should first focus on the reinforcement of the floor. Furthermore, only on the basis of ensuring a good foundation, the reinforcement of the floor structure can be accomplished well. Under the following situations floor structure reinforcement should be done.

(1) When the strength of the flat floor of the underground structure is not high enough, leading to its fracture due to ground expansion. (2) Due to rising underground water

level, the wall foundation sinks, the side walls move inward, and the vault is fractured.

There are three reinforcing methods:

(I) Addition of an Arch Facing Upward: A temporary lateral support is installed at the wall foundation. The original floor is crushed by machine or manually. Then, a steel reinforced concrete arch facing upward is freshly poured to limit the wall foundation from sinking further. Furthermore, it bears the upward pressure on the bottom. After the structure is stabilized, the seams of the structure are sealed and the internal layers are reinforced (See Figure 7).

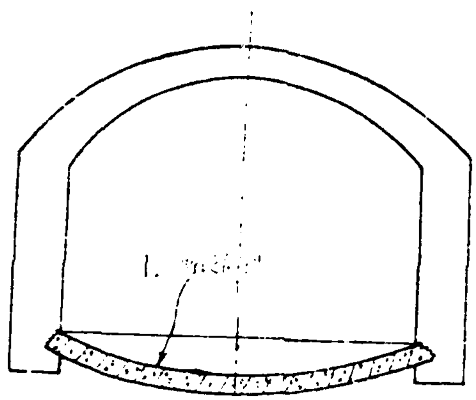

Fig. 7.

1. added face-up arch

(II) Increasing Cross-section of Floor: After brushing, cleaning, and applying a layer of high strength cement on the original floor, a new layer of freshly poured steel reinforced concrete is laid. The main steel bars are parallel to the original ones. They are also inserted into the load bearing wall to ensure its security at 30d to support the plate (See Figure 8).

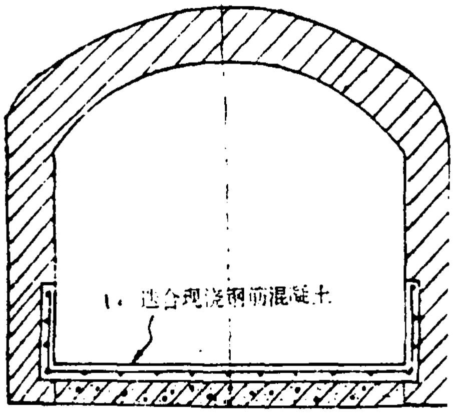

Fig. 8

1. freshly poured steel reinforced concrete

(III) Increasing Floor Support

(A) Changing a large span into small spans: Longitudinal and transverse steel reinforced concrete beams are added to the floor which does not have a sufficient resistance for a face-up arch (See Figure 9). (B) Changing a single floor into a supported plate from all sides: The original floor is brushed, washed, and pasted with a layer of high strength cement. An overlapping steel reinforced concrete layer is laid with longitudinal and transverse bars sticking into weight bearing and non-weight bearing walls to ensure the security of the steel bars at 30d.

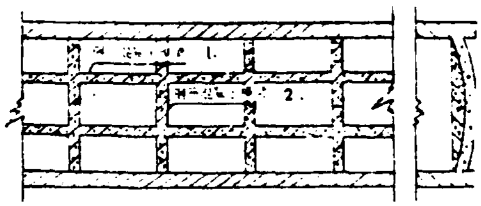

Fig. 9.

1. steel reinforced concrete longitudinal beam
2. steel reinforced concrete transverse beam

3. Reinforcement of Arch Support for Large Span Under-
Ground Structure

The force bearing situation of the structure is improved to limit the horizontal displacement of the arch supports. It is primarily used when the structure is cracked due to the action of a horizontal force on the arch support. There are two reinforcement methods: (A) Installation of Pull Rods at Arch Support: Pre-shaped steel anchors are used at the arch support. The spacing is approximately 2m. They are more closely placed near the damage area and farther apart in othe areas (See Figure 10). (B) Installation of Cement Blocks at the Arch Support: For a shallowly buried structure, the earth covering the arch support can be excavated. The foundation can be firmed up. Then, poured cement blocks can be used to balance the horizontal force acting on the arch support.

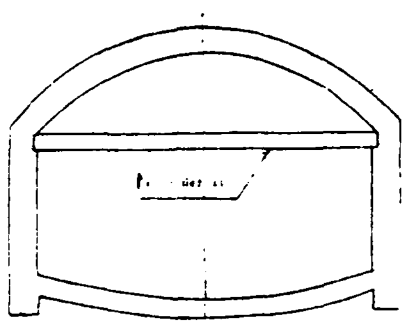

Fig. 10.

1. Pre-shaped Steel Pull Rod

4. Inner Jacket Reinforcement

(I) Hanging Mesh Injected (or Manual Mesh Pasted) Inner Jacket: It is used in a brick-laid structure in which a large area peeled off due to underground water, atmosphere, earthquake, or other vibration. When the usual repair work

cannot resolve the problem, hanging mesh injection can improve the integrity of the structure. The structural strength and seepage resistance are improved. It is an effective measure to prevent the weathering of the brick-laid structure and to protect the brick structure.

The First Layer: pure cement layer thickness 2-3 mm, water to cement 0.37-0.4.

The Second Layer: sand and cement mixture 5mm thick. Cement:sand = 1:2-3, water to cement ratio 0.35-0.45.

The Third Layer: 16# galvanized wire mesh is laid down, Ø 6-8 mm steel bar support is installed at an interval of 30cm.

The Fourth Layer: pure cement layer with same thickness /33
and water to cement ratio as the first layer.

The Fifth Layer: sand-cement mixture with same thickness mixing ratio, water to cement ratio as the second layer.

The Sixth Layer: pure cement layer, 3 mm thick, water to cement ratio 1:0.55-0.60.

Before injection (pasting), the substrate should be waterproofed and washed clean. The thickness must be uniform and the bonding must be secured. After the sandy cement hardens, a sprayer is used to moisten it during curing. The spray is done 2-3 times a day, for 14 days (See Figure 11).

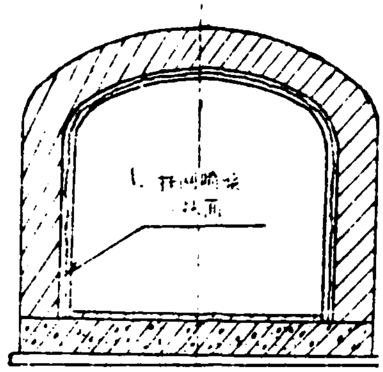

Fig. 11.

1. hanging mesh

(II) Freshly Poured Steel Reinforced Concrete Inner Jacket: It is a better reinforcing method to resist cracking, reinforce strength, and waterproof for an underground project which is thin in structure, low in strength, severe in deformation, and serious in water leakage. Leaks are first plugged from top to bottom. Then, a steel brush is used to remove the dust while highly pressurized water is used to wash it clean. A two-directional Ø 6-8 mm steel bars are meshed into a 10 cm mesh. It is riveted tight. 200# waterproof concrete is used in pouring into the mould. (Mixing ratio: cement:sand:crushed stone = 1:2:3, water to cement ratio 0.47-0.50). The thickness is usually more than 10 cm. The curing is not less than 14 days (See Figure 12).

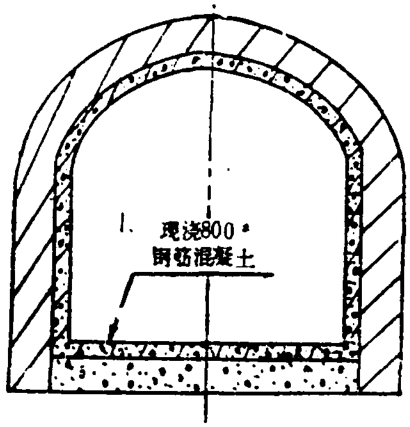

Fig. 12.
Key: Freshly poured 800# steel reinforced concrete.

Since 1978, we have repaired and reinforced some of the cracks and deformations in underground engineering projects already constructed. The structural strength, seepage resistance, and tightness of the structure have been improved to various extents. However, we just began our work. The methods used to repair and reinforce are not very mature. We welcome comments and corrections for our mistakes.

TUNNEL DIVISION OF CHINESE CIVIL ENGINEERING SOCIETY HELD ACADEMIC MEETINGS AND WATERPROOFING AND DRAINAGE

The waterprofing and drainage group of Chinese Civil Engineering Society held the first academic exchange meeting on August 15-20, 1982 in Guilin. Eighty-two delegates from various trades in the nation attended the meeting, representing 54 outfits. Thrity-eight papers and communications were received. This meeting included the contents of the "experience exchange meeting on the treatment of water leaks in operating railroad tunnelts" originally organized by the Institute of Design in the Ministry of Railroads and the "technical evaluation meeting on the waterproof seal of the experimental pipe in the subway system at Xinchun" planned by Shanghai Tunnel Construction Corporation. Sixteen reports were presented in the general meeting. Eight reports were read in group meetings.

With regard to repairing leaks, as far as the principle of water control, it is believed that a certain side should not be particularly emphasized. Instead, an overall treatment should be adopted for each case according to the hydrological geology of the loaction. In the area of waterproof sealant

materials, in in addition to using cement, water glass, and polyurethane sealant materials, cationic emusion asphalt has been gradually promoted in recent years. In the design and construction of new railroad tunnels, waterproofing has been taken more seriously. The Dayaoshan tunnel used polyvinyl chloride sheets as the waterproof layer. The Nanling tunnel used polyethylene sheet as the waterproof layer. Waterproof concrete used in both tunnels in areas with less water. Chloroprene emulsion cement coating was used as the waterproof layer in the Jinjiayan tunnel. Moreover, modified asphalt was used to protect it with some success. With regard to the economics and effectiveness of waterproof concrete, it is stressed that serious work must be done during construction, in addition to having a reasonable design. This is the key to ensuring the quality of waterproof concrete. Technical training, management, and supervision should be strengthened.

In order to prevent any freeze damage to the tunnels in cold areas, some articles described the construction methods and requirements of drainage ditches and waterproof gutters.

Modified water glass, LW type water soluble polyurethane, plastic water barrier strips, and "Shanghai ES cement" are relatively good waterproof materials. Some of them have already reached an advanced level. Attention must be addressed to the pollution problem of the chemical waterproof sealant materials. In addition to studying non-toxic, low-toxicity and low cost materials, the monitoring and evaluation of exisitng materials are also very important. An analysis done by the Institute of Hydroelectric Science in Zhejiang province indicated that underground water would not be polluted beyond the standards due to chromium in the sealant.

Reports on the Testing and Assembly of a Model QFS11 binary chemical sealant pump, a portable hand primed pump, and the rotor pumps and flowmeters of a binary sealant system were presented. These explored the technology of polyurethane chemical slurry and its parameters, the dual liquid binary

system chemical grouting and installing it in the openings.

They also listened to summaries by the various specialists on foreign tunnels from eastern Europe, western Europe and Japan and on introduction to techniques for preventing leakage in mines and tunnels.

They visited the site of Section #1 of the Bozhai tunnel at Guilin. They observed the spraying of emulsion asphalt, the painting of polyurethane tar, the laying of epoxy-polyurethane sealer, and a demonstration of the foaming when polyester slurry encounters water.

Actual experience indicates that cases are rare in which structural damage occurs due to faulty construction but again and again structural danage is seen which results from improper waterproofing. Therefore it was emphatically pointed out that it is not enough merely to pay attention to the structure and neglect waterproofing.

A distinguishing feature of this conference was that scientific achievements were introduced as well as the properties of waterproofing materials and equipment which are being produced. Some actual products were also displayed.

As this organization's second activity the conference tentatively decided to convene the "Conference of Waterproofing Technology" at a suitable time in 1984. When the time comes, the interested production units, construction units, design bureaus and scientific research units will participate, also related units which are invited to the meeting will supply actual items for comparison, evaluation and exchange.

The delegates also conducted a discussion of scientific and technical consulting servies, suggested that research be advanced in various areas, and enlarged and extended after acquiring experience.

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